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Radar Methods in Urban Environments

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14. ABSTRACT
We developed a new algorithm for sparse imaging of perfect electric conducting targets based on higher order sources or multipoles. We devised a strategy to select the optimal orders without needing any a priori information on the target by taking advantage of some analytical considerations in a canonical case. We developed a data-driven method for target detection in nonstationary environments. We employed drift detection algorithms to detect changes in the environment, which are utilized to intelligibly update the statistical detection algorithms to gain improved detection performance. We developed a method for joint design of amplitudes and frequency-hopping codes for frequency-hopping waveforms using a collocated multiple input/multiple output radar system. We formulated a novel game theory based model and propose
two joint design algorithms. We considered a system of two point scatterers under a general multistatic configuration and investigated the effect of multiple scattering in the detection and estimation of scatterers. We investigated the self-calibration problem for perturbed nested arrays in the presence of gain and phase errors, and developed robust algorithms to estimate the direction-of-arrivals (DOAs). We developed an adaptive Gaussian mixture learning algorithm in posterior-based distributed particle filtering, in which posteriors are approximated as Gaussian mixtures for wireless communication. We developed polynomial-time algorithms to compute the performance bounds on convex block-sparsity recovery based on fixed point theory and semidefinite programming. Recently, we also developed new target detection methods using weather radars and electromagnetic vector sensors. We analyzed the asymptotic DOA estimation
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Radar Methods in Urban Environments

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1 Final Accomplishments (August 2015 to July 2016)

We developed an innovative algorithm for sparse imaging of perfect electric conducting targets based on higher order sources or multipoles [J2]. EM imaging has emerged as a promising technology in the fields of radar, biomedical imaging, navigation, and remote sensing in recent years. We demonstrated that, due to the directivity of higher order sources, the imaging capabilities of the algorithm are enhanced. We showed that the zero-order sources are more suitable for the reconstruction of the convex parts of target boundaries, whereas the higher order sources are more appropriate for the concave parts of the boundaries. We devised a strategy to select the optimal orders without needing any a priori information on the target by taking advantage of some analytical considerations in a canonical case.

We developed a data-driven method for target detection in nonstationary environments [J4]. In our method, we employed drift detection algorithms to detect changes in the environment. We used incremental learning, particularly learning under concept drift algorithms, to learn the new statistical characteristics of the environment, which are then utilized to intelligibly update the statistical detection algorithms. We showed that our method can significantly improve the detection performance compared with detection techniques that are not aware of the environmental changes.

We developed a method for joint design of amplitudes and frequency-hopping codes for frequency-hopping waveforms using a colocated multiple input/multiple output (MIMO) radar system [J3]. We formulated the problem based on sparse recovery and the ambiguity function of the MIMO radar system for frequency-hopping waveforms. We proposed two strategies for amplitude design: amplitude design with separate constraints and amplitude design by fusing all transmitters. We formulated a novel game theory based model and propose two joint design algorithms, one applying a noncooperative scheme and the other applying a cooperative scheme. We demonstrated that the joint design method yields better combined code and amplitude matrices that result in improved performance over that of separate designs.

We investigated the effect of multiple scattering in the detection and estimation of scatterers in signal processing research [C2]. We considered a system of two point scatterers under a general multistatic configuration with multiple transmitters and multiple receivers. We analytically compared the Fisher information matrices when multiple scattering either exists or does not. We showed that when the two scatterers are in far-field locations and well-resolved, multiple scattering is favorable for the estimation.

We considered the problem of direction of arrival (DOA) estimation based on a nonuniform linear nested array in the presence of model errors [J1]. We investigated the self-calibration problem for perturbed nested arrays, and proposed corresponding robust algorithms to estimate both the model errors and the DOAs. We exploited the partial Toeplitz structure of the

covariance matrix to estimate the gain errors, and used the sparse total least squares to deal with the phase error issue. In addition, we provided the Cramér-Rao bound (CRB) to analyze the robustness of the estimation performance of the proposed approaches.

We considered the problem of adaptive Gaussian mixture learning in posterior-based distributed particle filtering, in which posteriors are approximated as Gaussian mixtures for wireless communication [J9, C1]. We developed a hierarchical clustering algorithm based on adaptive splitting, whose result is used as an initial guess for the expectation-maximization algorithm to obtain a local maximum likelihood solution. We showed that our method can provide higher accuracy with reduced the computation and communication cost in distributed particle filtering.

We developed algorithms to compute the performance bounds on convex block-sparsity recovery using fixed point theory and semidefinite programming [J5]. These computable performance bounds would open doors for wide applications in sensor arrays, radar, DNA microarrays, etc. We defined a family of quality measures such that the reconstruction errors of convex recovery algorithms are bounded in terms of these quality measures. We associate the quality measures with the fixed points of functions defined by a series of semidefinite programs, yielding polynomial-time algorithms with global convergence guarantees to compute these quality measures. We demonstrated that as long as the number of measurements is relatively large, these quality measures are bounded away from zero for a large class of random sensing matrices, a result parallel to the probabilistic analysis of the block restricted isometry property.

Recently, we also considered the problem of low-dimensional-model-based electromagnetic imaging [J12]. We developed target detection methods using weather radars and electromagnetic vector sensors [J13]. We investigated a new antenna structure named random frequency diverse arrays in active sensing [J7]. We analyzed the asymptotic DOA estimation performance of sparse linear arrays, such as co-prime and nested arrays, and derived the CRB [J8]. We derived the maximum-likelihood estimator (MLE) and the CRB for inertial sensor arrays [J6]. We developed a hypothesis testing framework based on the β-model and derived the corresponding MLE and CRB [J10]. We proposed a model for decision making under the influence of an artificial social network [J11].

2 Annual Archival Publications:

2.1 Journal Papers

J1. K. Han, P. Yang, and A. Nehorai, “Calibrating nested sensor arrays with model errors,” *IEEE Trans. on Antennas Propagat.*, Vol. 63, pp. 4739-4748, Nov. 2015.

J2. M. N. Stevanović, L. Crocco, A. R. Djordjević, and A. Nehorai, "Higher-order sparse microwave imaging of PEC scatterers," *IEEE Trans. Antennas Propag*., Vol. 64, pp. 988-997, Mar. 2016.

J3. K. Han and A. Nehorai, "Jointly optimal design for MIMO radar frequency-hopping waveforms using game theory," *IEEE Trans. on Aerospace and Electronic Systems*, Vol. 52, pp. 809-820, Apr. 2016.

J4. M. Akcakaya, S. Sen, and A. Nehorai, "A novel data-driven learning method for radar target detection in nonstationary environments," *IEEE Signal Processing Letters*, Vol. 23, pp. 762-766, May 2016.

J5. G. Tang and A. Nehorai, "Semidefinite programming for computable performance bounds on block-sparsity recovery," *IEEE Trans. on Signal Processing*, Vol. 64, pp. 4455-4468, Sept. 2016.

J6. I. Skog, J. Nilsson, P. Händel, A. Nehorai, "Inertial sensor arrays, maximum likelihood, and Cramér-Rao bound," to appear in *IEEE Trans. on Signal Processing*.

J7. Y. Liu, H. Ruan, L. Wang, and A. Nehorai, "The random frequency diverse array: a new antenna structure for uncoupled direction-range indication in active sensing," to appear in *IEEE Journal of Selected Topics in Signal Processing*.

J8. M. Wang and A. Nehorai, "Coarrays, MUSIC, and the Cramér Rao bound," to appear in *IEEE Trans. on Signal Processing*.

J9. J. Li and A. Nehorai, "Distributed particle filtering via optimal fusion of Gaussian mixtures," in revision for *IEEE Trans. on Signal and Information Processing over Networks*.

J10. J. Wahlström, I. Skog, P. S. La Rosa, P. Händel, and A. Nehorai, "The β-model, maximum likelihood, Cramér-Rao bounds, and hypothesis testing," submitted to *IEEE Trans. on Signal Processing*.

J11. A. Cassidy and A. Nehorai, "A model for decision making under the influence of an artificial social network," submitted to *Social Network Analysis and Mining*, Springer.

J12. L. Li, A. Nehorai, F. Xu, B. Zhang, T. Jin, and T. Cui, "A survey on the low-dimensional-model-based electromagnetic imaging," submitted to *Inverse Problems*.

J13. G. V. Prateek, M. Hurtado, and A. Nehorai, "Target detection using weather radars and electromagnetic vector sensor," submitted to *Signal Processing*.

2.2 Conference Papers

C1. J. Li and A. Nehorai, "Adaptive Gaussian mixture learning in distributed particle filtering," *Sixth IEEE International Workshop on Computational Advances in Multi-Sensor Adaptive Pro cessing (CAMSAP)*, Cancún, Mexico, Dec. 2015, 4 pages.

C2. G. Shi, A. Nehorai, H. Liu, B. Chen, and Y. Wang, "Multiple scattering effects on the localization of two point scatterers," *41th IEEE International Conference on Acoustics, Speech, and Signal Processing (ICASSP)*, Shanghai, China, Mar. 2016, 5 pages.

3 Awards and Honors

1. Jichuan Li (PhD student), was selected the NSF travel award for *Sixth IEEE International Workshop on Computational Advances in Multi-Sensor Adaptive Processing (CAMSAP)*, Cancún, Mexico, Oct. 2015.

4 Dissertations

1. Jichuan Li, "Distributed target tracking and synchronization in wireless sensor networks," Washington University in St. Louis, 2016.

5 Relevant Placements of PhD Graduates

1. Jichuan Li (PhD, 2015) is a Software Engineer, Google Inc., Mountain View, California.

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Abstract

We developed a new algorithm for sparse imaging of perfect electric conducting targets based on higher order sources or multipoles. We devised a strategy to select the optimal orders without needing any a priori information on the target by taking advantage of some analytical considerations in a canonical case. We developed a data-driven method for target detection in nonstationary environments. We employed drift detection algorithms to detect changes in the environment, which are utilized to intelligibly update the statistical detection algorithms to gain improved detection performance. We developed a method for joint design of amplitudes and frequency-hopping codes for frequency-hopping waveforms using a colocated multiple input/multiple output radar system. We formulated a novel game theory based model and propose two joint design algorithms. We considered a system of two point scatterers under a general multistatic configuration and investigated the effect of multiple scattering in the detection and estimation of scatterers. We investigated the self-calibration problem for perturbed nested arrays in the presence of gain and phase errors, and developed robust algorithms to estimate the direction-of-arrivals (DOAs). We developed an adaptive Gaussian mixture learning algorithm in posterior-based distributed particle filtering, in which posteriors are approximated as Gaussian mixtures for wireless communication. We developed polynomial-

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Archival Publications (published) during reporting period:

Book Chapters:

1. P. Chavali and A. Nehorai, "Urban target tracking using sparse representations," in Compressive Sensing for Urban Radar, (Ch. 10, pp. 327-359, M. Amin, Ed.) CRC, 2014.

2. A. Nehorai and G. Tang, "Bounds on parametric estimation," in Encyclopedia of Systems and Control, J. Baillieul and T. Samad, Ed., 1st ed. London, UK: Springer London, 2015, sec. 69-2, pp. 1-8.

Journal Papers:

1. P. Chavali and A. Nehorai, "Scheduling and resource allocation in a cognitive radar network for multiple-target tracking," IEEE Trans. on Signal Processing, Vol. 60, pp. 715-729, Feb. 2012.

2. S. Gogineni and A. Nehorai, "Game theoretic design for polarimetric MIMO radar target detection," Signal Processing, Vol. 92, No. 5, pp. 1281-1289, May 2012.

3. S. Gogineni and A. Nehorai, "Frequency-hopping code design for MIMO radar estimation using sparse modeling," IEEE Trans. on Signal Processing, Vol. 60, pp. 3022-3035, Jun. 2012.

4. M. M. Nikolic, A. Nehorai, and A. R. Djordjevic, "Estimation of direction of arrival using arrays on platforms," IEEE Trans. on Antennas Propagat, Vol. 60, pp. 3444-3454, Jul. 2012.

5. P. Chavali and A. Nehorai, "A low-complexity multi-target tracking algorithm in urban environments using sparse modeling," Signal Processing, Vol. 92, pp. 2199-2213, Sep. 2012.

6. P. Chavali and A. Nehorai, "Managing multi-modal sensor networks using price theory," IEEE Trans. on Signal Processing, Vol. 60, pp. 4874-4887, Sep. 2012.

7. G. Tang and A. Nehorai, "The stability of low-rank matrix reconstruction: a constrained singular value view," IEEE Trans. on Information Theory, Vol. 58, pp. 6079-6092, Sep. 2012.

8. P. Chavali and A. Nehorai, "A low-complexity multi-target tracking algorithm in urban environments using

sparse modeling," Signal Processing, Vol. 92, pp. 2199-2213, Sep. 2012.

9. M. M. Nikolic, A. Nehorai, and A. R. Djordjevic, "Electromagnetic imaging of hidden 2D PEC targets using sparse signal modeling," IEEE Trans. Geosci. Remote Sens. Vol. 51, No. 5, pp. 2707-2721, May 2013.

10. P. Yang, G. Tang, and A. Nehorai, "A game-theoretic approach for optimal time-of-use electricity pricing," IEEE Trans. on Power Systems. Vol. 28, No. 2, pp. 884-892, May 2013.

11. P. Chavali and A. Nehorai, "Concurrent Particle Filtering and Data Association Using Game Theory for Tracking Multiple Maneuvering Targets," IEEE Trans. on Signal Processing, Vol. 61, pp. 4934-4948, Oct. 2013.

12. K. Han and A. Nehorai, "Wideband Gaussian Source Processing Using a Linear Nested Array," IEEE Signal Processing Letters, No. 11, pp. 1110-1113, Nov. 2013.

13. M. Hurtado, C.H. Muravchik and A. Nehorai, "Enhanced Sparse Bayesian Learning via Statistical Thresholding for Signals in Structured Noise," IEEE Trans. on Signal Processing, Vol.61, pp. 5430-5443, Nov. 2013.

14. K. Han and A. Nehorai, "Improved Source Number Detection and Direction Estimation with Nested Arrays and ULAs Using Jackknifing," IEEE Trans. on Signal Processing, Vol. 61, pp. 6118-6128, Dec. 2013.

15. Z. Tan and A. Nehorai, "Sparse Direction of Arrival Estimation Using Co-Prime Arrays with Off-Grid Targets," IEEE Signal Processing Letters, Vol. 21, pp. 26-29, Jan. 2014.

16. S. Gogineni, M. Rangaswamy, B.D. Rigling and A. Nehorai, "Cramér-Rao Bounds for UMTS-Based Passive Multistatic Radar," IEEE Trans. on Signal Processing, Vol. 62, pp. 95-106, Jan. 2014.
17. P. Chavali and A. Nehorai, "Hierarchical particle filtering for multi-modal data fusion with application to multiple-target tracking," Signal Processing, Vol. 97, pp. 207-220, Apr. 2014.

18. Z. Tan, Y. C. Eldar, A. Beck and A. Nehorai, "Smoothing and Decomposition for Analysis Sparse Recovery," IEEE Trans. on Signal Processing, Vol. 62, pp. 1762-1774, Apr. 2014.

19. K. Han and A. Nehorai, "Nested Vector-Sensor Array Processing via Tensor Modeling," IEEE Trans. on Signal Processing, Vol. 62, pp. 2542-2553, May 2014.

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22. Z. Tan, P. Yang, and A. Nehorai, "Joint sparse recovery method for compressed sensing with structured dictionary mismatch," IEEE Trans. on Signal Processing, Vol. 62, pp. 4997-5008, Oct. 2014.

23. Z. Tan, Y. Eldar, and A. Nehorai, "Direction of arrival estimation using co-prime arrays: a super resolution viewpoint," IEEE Trans. on Signal Processing, Vol. 62, pp. 5565-5576, Nov. 2014.

24. G. Tang and A. Nehorai, "Computable performance bounds on sparse recovery," IEEE Trans. on Signal Processing, Vol. 63, pp. 132-141, Jan. 2015.

25. P. Chavali and A. Nehorai, "Distributed power system state estimation using factor graphs," IEEE Trans. on Signal Processing, Vol. 63, pp. 2864-2876, June, 2015.

26. K. Han, P. Yang, and A. Nehorai, "Calibrating nested sensor arrays with model errors," IEEE Trans. on Antennas Propagat., Vol. 63, pp. 4739-4748, Nov. 2015.

27. M. N. Stevanović, L. Crocco, A. R. Djordjević, and A. Nehorai, "Higher-order sparse microwave imaging of PEC scatterers," IEEE Trans. Antennas Propag., Vol. 64, pp. 988-997, Mar. 2016.

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38. G. V. Prateek, M. Hurtado, and A. Nehorai, "Target detection using weather radars and electromagnetic vector sensor," submitted to Signal Processing.

Conference Papers:

1. S. Gogineni and A. Nehorai, "Adaptive waveform design for colocated MIMO radar using sparse modeling," Proc. 4th IEEE Intl. Workshop on Computational Advances in Multi-Sensor Adaptive Processing (CAMSAP), pp. 13-16, San Juan, Puerto Rico, Dec. 13-16, 2011. (Invited)

2. S. Gogineni and A. Nehorai, "Polarimetric MIMO radar target detection using game theory," Proc. 4th IEEE Intl. Workshop on Computational Advances in Multi-Sensor Adaptive Processing (CAMSAP), pp. 17-20, San Juan, Puerto Rico, Dec. 13-16, 2011. (Invited)

3. P. Yang, G. Tang and A. Nehorai, "Sparsity enforced regression based on over-complete dictionary," in Proc. 4th Intl. Workshop on Computational Advances in Multi-Sensor

Adaptive Processing (CAMSAP), San Juan, Puerto Rico, pp. 261-264, Dec. 13-16, 2011.

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7. S. Gogineni and A. Nehorai, "Frequency-hopping code design for colocated MIMO radar using sparse modeling," Proc. 6th Int. Waveform Diversity and Design (WDD) Conf., pp. 54-58, Kauai, Hawaii, USA, Jan. 2012.

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14. M. Nikolic, A. Nehorai, and A. Djordjevic, "Two-step (estimate and detect) sparse imaging," IEEE Antennas and Propagation Society International Symposium (APSURSI), Chicago, IL, Jul. 2012, pp. 1-2.

15. W. F. Zhang, P. Yang, D. Q. Dai, and A. Nehorai, "Reflectance estimation using local regression methods," Proc. 9th Intl. Symp. on Neural Networks (ISNN), Shenyang, China, Jul. 2012, pp. 116-122.

16. P. Chavali and A. Nehorai, "Distributed data association via game theory", Proc. IEEE Radar Conference, Ottawa, ON, Canada, Apr. 2013.

17. S. Gogineni, A. Nehorai, and M. Rangaswamy, "Multi-functional OFDM waveform design," Proc. IEEE Radar Conference, Ottawa, ON, Canada, Apr. 2013.

18. K. Han and A. Nehorai, "Joint frequency-hopping waveform design for MIMO radar estimation using

game theory," Proc. IEEE Radar Conference, Ottawa, ON, Canada, Apr. 2013.

19. M. Nikolic, A. Nehorai, A. R. Djordjevic, and S. Nikolaou, "Breast-tumor shape estimation using the jump-diffusion algorithm," Proc. of the 7th European Conference on Antennas and Propagation (EUCAP), Gothenburg, Sweden, Apr. 2013, pp. 1093-1094.

20. E. Gilboa, P. Chavali, P. Yang, and A. Nehorai, "Distributed optimization via adaptive regularization for large problems with separable constraints," Proc. International Conference on Acoustics, Speech, and Signal Processing (ICASSP), Vancouver, Canada, May. 2013.

21. Z. Tan, P. Yang, and A. Nehorai, "Sparse MIMO radar with phase mismatch," Proc. International Conference on Acoustics, Speech, and Signal Processing (ICASSP), Vancouver, Canada, May. 2013.

22. M. Nikolic, A. Nehorai, S. Nicolaou, and A. R. Djordjevic, "Electromagnetic imaging of breast tumor using jump-diffusion," 2013 IEEE International Symposium on Antennas and Propagation and USNC-URSI National Radio Science Meeting (APSURSI), Orlando, Florida, USA, Jul. 2013.

23. K. Han and A. Nehorai, "Source number detection with nested arrays and ULAs using jackknifing," Computational Advances in Multi-Sensor Adaptive Processing (CAMSAP), 2013 IEEE 5th International Workshop on, Dec. 15-18, 2013, pp. 57-60.

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25. Z. Tan, P. Yang and A. Nehorai, "Joint-sparse recovery in compressed sensing with dictionary mismatch," Computational Advances in Multi-Sensor Adaptive Processing (CAMSAP), 2013 IEEE 5th International Workshop on, Dec. 15-18, 2013, pp.248-251.

26. S. Gogineni, M. Rangaswamy, B. Rigling, and A. Nehorai, "Cramer-Rao bound analysis for passive multistatic radar using UMTS signals," Proc. IEEE Radar Conf., Cincinnati, USA, May. 2014.

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New discoveries, inventions, or patent disclosures:

Do you have any discoveries, inventions, or patent disclosures to report for this period?

No

Please describe and include any notable dates

Do you plan to pursue a claim for personal or organizational intellectual property?

Changes in research objectives (if any):

None

Change in AFOSR Program Officer, if any:

Dr. Arje Nachman

Extensions granted or milestones slipped, if any:

None

AFOSR LRIR Number

LRIR Title

Reporting Period

Laboratory Task Manager

Program Officer

Research Objectives

Technical Summary

Funding Summary by Cost Category (by FY, $K)

	Starting FY	FY+1	FY+2
Salary			
Equipment/Facilities			
Supplies			
Total			

Report Document

Report Document - Text Analysis

Report Document - Text Analysis

Appendix Documents

2. Thank You

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